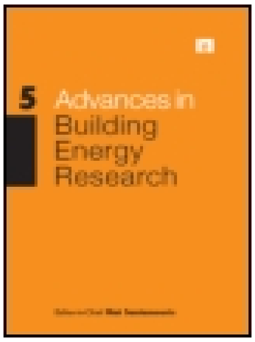

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Imran Khan

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Household factors and electrical peak demand: a review for further assessment

Imran Khan [a,b,c]

[a]Centre for Sustainability, University of Otago, Dunedin, New Zealand; [b]Department of Physics, University of Otago, Dunedin, New Zealand; [c]Department of Electrical and Electronic Engineering, Jashore University of Science and Technology, Bangladesh

ABSTRACT

At least one-third of the total electricity generation of a country is consumed by the residential sector, which is one of the most unpredictable consumer groups with respect to electricity usage and thus risks network security by producing peaks in demand. Consequently, a growing body of literature has paid particular attention to this sector and explored the household factors responsible for residential electricity consumption. However, comprehensive studies that explicitly considered all these factors in relation to peaks in demand have rarely been undertaken. A comprehensive review of the factors that contribute to residential electricity consumption has thus been conducted. Possible links between these factors and peaks in demand are investigated. As part of this review, in-house energy-use dynamics are presented, and a framework for future studies is introduced. The results of this review would serve as a useful reference to engage in new research dealing with residential factors and peaks in electrical demand.

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Residential electricity consumption; residential energy-use factors; in-house energy-use dynamics; residential electrical energy profiling; electrical peaks in demand

1. Introduction

Reduction in total residential electrical energy consumption to improve economic and environmental outcomes has been a focus of research interest in recent years (Andersen, Baldini, Hansen, & Jensen, 2017; Fan, MacGill, & Sproul, 2017; Holzmann & Schmid, 2018; Jaffar, Oreszczyn, Raslan, & Summerfield, 2018; Khan, 2019b; Khan, Jack, & Stephenson, 2017; Latif, Shabani, Esser, & Martkovich, 2017; Lévy & Belaïd, 2018; Li, Song, & Kaza, 2018; McLoughlin, Duffy, & Conlon, 2015; Torriti, Hanna, Anderson, Yeboah, & Druckman, 2015). However, much less attention has been paid to electrical peak demand, which predominantly arises from residence due to different household factors associated with electricity consumption (Fan et al., 2017). Electrical demand derived from residences creates more demand variation than industrial and commercial sectors. Industrial and commercial electricity use is relatively predictable and almost constant, whereas residential use is variable in nature (Electricity Authority, 2014; U.S. EIA, 2013). Although it may vary from country to country, in general, residential electrical energy demand is at least about

CONTACT Imran Khan ikr_ece@yahoo.com; i.khan@just.edu.bd Centre for Sustainability, University of Otago, Dunedin, New Zealand

one-third of the total electricity demand of a country. For example, in New Zealand, residential electrical energy demand was 32% in 2014 (Electricity Authority, 2016). In Western countries, building sector's energy consumption varies from 40 to 68% (Lun & Ohba, 2012).

Although a number of demand-side management (DSM) strategies, including time of use (TOU) pricing, have been employed to reduce peak residential demand, these have met with limited success (Nicholls & Strengers, 2015; Torriti, 2016). Residential electricity use is driven by a complex network of time-dependent physical and social factors and a better understanding of these underlying factors is critical to developing more effective electrical peak demand management strategies. The question remains, what are the factors contributing to residential electrical peak demand? According to Torriti (2016, p. 3)-

> The answer is simple and complicated at the same time. It is the people: what people do and when they do it. Peak demand is not determined by individuals' desire to consume energy at a given point of the day, but by the way people's days are structured, which is partly in their hands (routines and habits), but partly defined by the obligations and social structure of time (schedules and social practices). (Torriti, 2016)

In other words, some factors that contribute to electrical peak demand are directly related to people, and others are embedded in a wider social context. The focus of this review is to identify the factors from residences that are responsible for total household electricity consumption and investigate their relation to peak demand.

Additionally, balancing supply and demand [generations from intermittent renewables and fossil fuels (Khan, 2019a)] will become challenging in the near future due to the mixture of peak demands, such as the projected proliferation of electric vehicles and air conditioners, reduced base load due to efficient technology development, and declining electricity utilization through energy conservation strategies (Boßmann & Staffell, 2015; Khan, Jack, & Stephenson, 2018). At the same time, electrical network capacity cannot be instantly increased to meet these variable peaks. Moreover, importing electricity from neighbouring countries is costly and not always feasible. Under all of these circumstances, it is necessary to focus more on electrical peak demand, and in particular, understanding the underlying reasons of residential electrical peak demand. This understanding will help power companies and network operators to take related measures and develop policy to mitigate electrical peak demand at its origin to ensure more effective peak demand management strategies.

Ample evidence exists to show that electrical peak demand has captured researchers' interest, particularly in managing electrical peaks in the network through different DSM strategies (Aalami, Yousefi, & Parsa Moghadam, 2008; Dupont, Dietrich, De Jonghe, Ramos, & Belmans, 2014; FERC, 2006; Laicane, Blumberga, Blumberga, & Rosa, 2015; Marwan & Kamel, 2011; Newsham & Bowker, 2010; Nicholls & Strengers, 2015; Powells, Bulkeley, Bell, & Judson, 2014; Spees & Lave, 2008; Taylor & Taylor, 2015). Most of the DSM strategies are based on real time load management schemes, either at consumers' end (e.g. time of use) or at network operators' end (e.g. controlling load through switching). Although DSM strategies have been applied to manage electrical peak demand, these have limitations. For instance, Nicholls and Strengers (2015) have found time of use tariff is not effective for families with children in Australia. This indicates that further research is essential in order to identify underlying potential drivers that create electrical peaks in demand from residences and what risks are involved for the network security over relatively short periods. As a consequence, related measures can be taken to develop more effective electrical peak demand management strategies. Hence, a review of these available factors could be a worthwhile starting point for further research, which seems absent in the existing literature.

Most studies have paid attention to residential electrical energy consumption rather than electrical peak demand, and less attention still has been paid to exploring the direct relation between driving factors and electrical peak demand at residences. For instance, an extensive list of factors were identified and the correlations between these factors and residential energy consumption were established through fishbone diagram method in the USA; however, the relation between the factors and electrical peak demand were not explored in that study (Bhattacharjee, Reichard, McCoy, Pearce, & Beliveau, 2014). Although a few studies have tried to explore the links between peak demand and climatic conditions such as temperature and wind, and the impact of household appliances, many other possible potential driving factors of electrical peak demand remain unexplored, such as peoples' activities associated with their socio-demographic characteristics (Barker, Mishra, Irwin, Shenoy, & Albrecht, 2012; Caprino, Della Vedova, & Facchinetti, 2014; Dirks et al., 2015; Dlamini & Cromieres, 2012; Hong, Chang, & Lin, 2013; Mirlatifi, Egelioglu, & Atikol, 2015; Rhodes, Stephens, & Webber, 2011; Sekar, Williams, & Chen, 2016). One of the reasons could be the assumption that the causes of peaks are well known, such as temperature, in-house appliance use, and occupants' behaviour. This review examines the many factors that contribute to residential electrical energy consumption and highlights any relations between these factors and residential electrical peak demand.

The article is organized as follows: Section 2 explains the effect of electrical peak demand on electrical networks and associated costs. Section 3 provides insights from the literature on different potential factors that contribute to residential electrical energy consumption. Section 4 discusses the findings. Section 5 indicates the implications for future studies and illustrates a framework towards residential electrical energy-use profiling based on this review, and the final section concludes the article.

2. Electrical peak demand and cost

When electricity demand at a particular time or period of time exceeds normal capacity of the electrical network, peaks in demand are created. Electrical peak demand occurs on a number of different timescales and is categorized as daily, monthly, seasonal, annual, and event associated. Although peak demand occurs around 1% of annual hours, it affects networks' stability, security, reliability and most importantly the cost of energy (Palmer, 2014). All power plants in the generation fleet do not run continuously at full capacity. Power plants supporting base demand or base load run continuously throughout the year except for maintenance periods. To achieve a high aggregate reliability of the fleet, individual generators can produce power when it is required even for a few hours in a year during peak time.

The S-shaped load duration curve (LDC) is used to explain the electrical network's demand characteristics. LDC is a graphic illustration that shows the percentage of time electrical network is proximate to peak demand. This curve depicts demand or load (y-axis) scenarios with respect to time duration (x-axis), usually over a year. For any electrical network, base demand or load (in GW) is approximately 45% to 75% for most of the year.

Above base demand, the next 20% consists of intermediate demand. The final top 5% represents peak demand, which exists only over 1% of annual hours (Palmer, 2014). The area under LDC corresponds to annual energy demand. For instance, consider the load duration curve of New Zealand electricity demand for 2015 in Figure 1. The LDC in Figure 1 is in line with LDC as explained in (Palmer, 2014; Wiskich, 2014). However, peak load (~7%) exists over 2.5% of annual hours in the case of New Zealand for 2015. In 2014, annual peak load hours were 1.75%.[1] Network 'peakiness' is characterized by a sharp upward turn on the left part of the load duration curve (cf., Figure 1): a sharper curve characterizes a peakier network, and a threat to network security (Khan, 2018). At the same time, peakiness of the network decreases the overall efficiency of the electricity generation system as peaking power plants will only be productive during peak hours.

Although peak load is a tiny portion of LDC, it costs millions of dollars at system level (e.g. peaking power plant establishment, operation and maintenance). For example, overnight capital costs (excluding transmission and distribution cost) of natural gas fired generation is about USD 1289/kWe (~NZD 1780/kWe) for New Zealand (NEA & IEA, 2015), which is in line with the finding of New Zealand Electricity Commission (Electricity Commission, 2008). On the other hand, it was found that on average a kW costs NZD 187 per year, which includes generation ($125), transmission ($24) and network ($38) costs. Thus, peak demand of 0.45 GW will cost NZD 84.15 million per year (considering peak load in Figure 1). Additionally, peaking power plants have low capacity (generating output below 100 MW) and it has been found that power plants with lower capacity cost more money to generate one unit of electricity.[2]

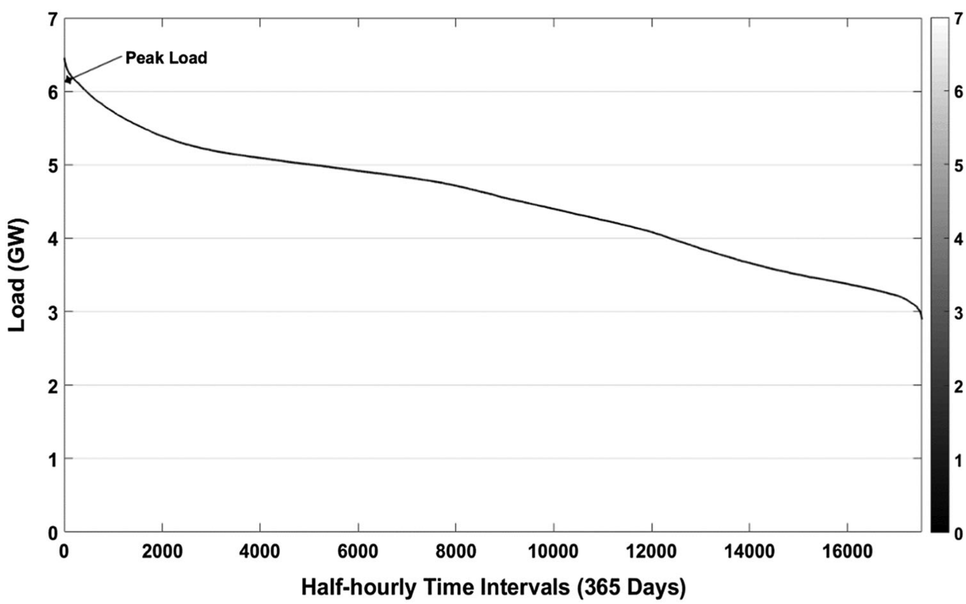

Figure 1. Load duration curve of New Zealand electricity systems for the year of 2015. Base, intermediate, and peak load vary between 4.5–5, 5.5–6, and 6–6.5 GW, respectively (Khan et al., 2018). (Data source: New Zealand Electricity Authority).

Network augmentation cost is driven by a few critical peak demand events, which are progressively driven by residential electricity demand. To cater for these relatively short-lived peak events, network operators tend to increase grid capacity by building new generation systems, which results in curtailment in average asset utilization (i.e. network infrastructure), and placing an ascendant pressure on electricity prices (Quezada, Grozev, Seo, & Wang, 2014). Electrical network infrastructure cost recovery is solely dependent on electrical energy consumption by consumers. The maximum utilization of network infrastructure is calculated on base demand with the lowest average sale price. However, peak demand achieves a highest average sale price but minimum network utilization. Time-varying and hourly end-consumer electricity tariff equations also show a similar result (Oldewurtel, Ulbig, Parisio, Andersson, & Morari, 2010; Ulbig & Andersson, 2010). An electricity tariff equation can be written as [Oldewurtel et al. (2010, p. 1929)]:

$$Tariff\ (i) = \left(\alpha * \frac{Spot\ Price\ (i)}{Spot\ Price_{avg}} + \beta * \frac{Load\ Level\ (i)}{Load\ Level_{avg}} + \gamma\right) * Tariff_{avg} \tag{1}$$

Where-
Tariff (*i*): Hourly end-consumer electricity tariff for ith hour;
Spot Price (*i*): Spot electricity price during the ith hour;
$Spot\ Price_{avg}$: Average spot electricity price;
Load Level (*i*): Level of the load for ith hour;
$Load\ Level_{avg}$: Average load level;
$Tariff_{avg}$: Average tariff;
α:% Electricity_{avg} (i.e. cost of electricity provision over a full year);
β:% Grid Utilisation_{avg} (i.e. costs for grid utilization);
γ:% City Concession_{avg} (i.e. concession fee for the region) [all weighted averages].

It is clear from Equation (1) that if the spot price remains unchanged and only the load increases, hourly tariff also increases. Importantly, spot prices also increase during peak hours. As a consequence, hourly tariffs increase sharply during peak hours. All other parameters in Equation (1) remain almost constant during peak periods.

Therefore, if electricity tariff is increased due to peak time generation, this will need to be paid by all consumers, regardless of their contribution to peak demand. Hence, research is needed to identify types of consumers, particularly households with different potential factors that contribute to electrical peak demand. Subsequently, related measures can be taken for those 'peaky' households towards more effective electrical peak demand mitigation.

3. Factors driving residential electricity consumption

Previous studies have identified different factors contributing to residential electricity demand or consumption by using top-down [e.g. (Blázquez, Boogen, & Filippini, 2013)] or bottom-up [e.g. (Bedir, Hasselaar, & Itard, 2013; McLoughlin, Duffy, & Conlon, 2012)] approaches, often both (Wiesmann, Lima Azevedo, Ferrão, & Fernández, 2011). A top-down approach deals with national level data and tries to obtain data from households considering different household characteristics. The bottom-up approach considers individual households' characteristics and extrapolates to the total housing stock (Grandjean, Adnot, & Binet, 2012).

The following subsections discuss the factors as identified in the literature that are directly or indirectly related to residential electrical energy consumption. It should be borne in mind that this review focuses on residential electrical energy consuming factors and attempts to identify possible relations between these factors and electrical peak demand.

3.1 Climate and location of the dwelling

Electricity demand fluctuates during the day, across the week and on a seasonal basis (Gavin, 2014). Residential electricity demand changes due to variations in weather conditions, such as extremely hot or cold weather. Irregular climatic change, such as a sudden heat wave in a temperate climatic region, which requires space cooling, can affect electricity demand. The location of a country is one of the key factors underlying seasonal residential and network peak demand. Notably, seasonal daily residential electricity demand varies from one country to another. For example, daily electricity demand in winter is on average 36% higher than on a summer day in the UK (Gavin, 2014). On the other hand, in hot locations such as Hong Kong, Qatar, and California, USA daily electricity demand on a hot summer day is higher than on a winter day (Gastli, Charabi, Alammari, & Al-Ali, 2013; Lam, Tang, & Li, 2008; Lee & Medina, 2016).

A number of studies have found a relationship between climate and electrical energy consumption using the multiple regression technique (Kros, 2015; Lam, 1998; Lam et al., 2008; Lam, Tsang, Yang, & Li, 2005; Munoz & Sailor, 1997; Yee Yan, 1998). Sailor (2001) has reported that daily or seasonal climatic changes affect annual per capita electrical energy consumption of different states in the USA in diverse ways. For example, he found that change of wind speed in association with global climate change has a marginal impact on per capita change in annual electrical energy consumption. Per capita change in annual energy consumption only occurs when wind speed increases significantly during a month.

Pardo, Meneu, and Valor (2002) developed a model to predict electricity demand using the daily heating and cooling degree method, and found a direct impact of season and temperature on electricity demand. Similarly, Kros (2015) investigated seasonal influences on electricity demand in the mid-Atlantic region and found two main factors that affect electricity demand: temperature and the seasons. In Hong Kong, Tso and Yau (2003) found a similar seasonal impact on electrical energy demand.

In an early study, Yee Yan (1998) investigated the impact of cloud and humidity on electricity consumption in Hong Kong and found an effect of cloud cover on electricity consumption in summer: cloud cover was negatively related to residential electricity consumption. If the sky is clear, residential electricity consumption is higher, due to the use of cooling appliances. Cloud is thus an indirect factor behind residential electricity consumption, as it is associated with temperature; however, the author did not find any relationship between humidity and residential electricity consumption (Yee Yan, 1998). In line with (Yee Yan, 1998), Gastli et al. (2013) in Qatar also found almost no effect of humidity on electricity demand, but only temperature; the correlation between temperature and electricity demand was found to be linear. In contrast, a non-linear relationship between external temperature and residential electricity demand has been found in the USA and Europe (Salari & Javid, 2016; Torriti, 2016).

Geographical location (i.e. latitude and longitude) of residences has a significant impact on residential electricity consumption. Bartusch, Odlare, Wallin, and Wester (2012) chose three locations in Sweden for their study and found a statistically significant relation between location and residential electrical energy consumption (Bartusch et al., 2012). By the same token, a study conducted in China found a strong relationship between temperature and latitude during winter, which in turn was responsible for residential electrical energy consumption through in-house air conditioning (Lu, Wang, Kang, & Pang, 2009). In contrast, Yohanis, Mondol, Wright, and Norton (2008) conducted a study in different locations – city, town and village – in Northern Ireland, and did not find any significant effect of location on residential electrical energy consumption.

A direct impact of temperature on electrical peak demand was reported in Brisbane, Australia (Oliver, Martin, Krause, Bartlett, & Froome, 2015); if the temperature increases by 1 °C, electrical peak demand increases about 2%. In the same vein, Parkpoom and Harrison (2008) reported that if temperature increases from 1.74–3.43 °C, peak electricity demand would increase by 1.5% to 3.1% in 2020, 3.7% to 8.3% in 2050, and 6.6% to 15.3% in 2080 in Thailand. Although these results are predictive, they clearly show the relationship between electrical peak demand and temperature, a climatic factor. Furthermore, Fung, Lam, Hung, Pang, and Lee (2006) found a relation between ambient temperature rise and domestic electricity consumption, which can be explained by a power 2 polynomial function. The authors stated that electricity consumption was increased by 9.2% because of an ambient temperature increase of 1 °C (Fung et al., 2006). Similarly, it was found in the USA, if temperature increases by 1 °C, the impacts on annual per capita electrical energy consumption would be 1.8%, 5.3%, 0.4%, and 2.6% for California, Florida, New York and Texas, respectively (Sailor, 2001).

Overall, the evidence presented in this section from the literature review suggests that there exists a direct relationship between residential electrical energy consumption and climatic conditions. The main climatic factor responsible for residential electrical energy consumption is temperature, whereas, wind and humidity have a marginal or insignificant impact. On the other hand, geographical location of residences also plays a vital role in household electrical energy consumption, as it is linked to climate.

3.2 Physical characteristics of dwelling

Previous research studies confirmed that a dwelling's physical characteristics make a major contribution to residential electricity consumption. Relevant characteristics include size (number of rooms and floors, floor area); type of dwelling (degree of detachment from surrounding structures), building materials (e.g. insulation), and age of the dwelling. In addition, the surface area to volume ratio (S/V) of a dwelling is also an important characteristic, which is related to heat transfer for that dwelling (Ko, 2013). A recent study by Kavousian, Rajagopal, and Fischer (2012) in the USA has reported that physical characteristics of dwellings are responsible for about 2-5% of total residential electrical energy consumption.

A growing body of literature has investigated residential electricity consumption with respect to floor area of dwellings (Bedir et al., 2013; Tso & Guan, 2014; Gouveia & Seixas, 2016; Kavousian, Rajagopal, & Fischer, 2012; Lam, 1996; McLoughlin et al., 2012; Tso & Yau, 2003; Tso & Yau, 2007; Yohanis et al., 2008). For example, Yohanis et al. (2008) found that average electrical energy consumption per square metre varies from 2.5–5 kWh in UK dwellings. Similarly, Tso and Guan (2014) reported that if mean dwelling size is increased by one square foot from the divisional average dwelling size in the USA, residential energy consumption increases by 488791 kWh/year. Despite prior evidence, Bedir et al. (2013) did not find any significant relation between floor area and electrical energy consumption in the Netherlands. Alternately, dwelling size can also be defined according to the number of bedrooms, which also contributes to residential electrical energy demand. For instance, McLoughlin et al. (2012) found that an additional bedroom would add on average 0.23 kW power to the existing demand in Irish dwellings.

Dwelling type, such as degree of detachment (Yohanis et al., 2008), public rental, government subsidized, private, and village house (Tso & Yau, 2007) is interpreted in different ways in a number of studies and found to be significant towards residential electrical energy consumption (Bedir et al., 2013; Li et al., 2018; McLoughlin et al., 2012), and peak demand (Fan et al., 2017). For instance, Li et al. (2018) found that neighbourhood density is negatively related to summer residential electricity consumption in China, which is associated with dwelling type.

Traditionally, it has been argued that dwelling age is an insignificant factor in residential electrical energy consumption (McLoughlin et al., 2012; Powers, Swan, & Lee, 1992; Tso & Yau, 2003; Tso & Yau, 2007). On the contrary, a Swedish study showed that residential energy consumption varies depending on dwelling age (Bartusch et al., 2012). The study was conducted in three different locations in Sweden and revealed that residential energy consumption in houses that were built before the 1980s consume more energy than houses built after 1980. Another study also found buildings age dependency on residential energy consumption for Hellenic residential buildings in Greece (Droutsa, Kontoyiannidis, Dascalaki, & Balaras, 2014). Similarly, a clear relationship was found between age of dwelling and in-house temperature, which in turns is related to energy consumption due to heating or cooling activities in New Zealand dwellings (Isaacs et al., 2010). Unlike (Droutsa et al., 2014) and (Bartusch et al., 2012), O'Doherty, Lyons, and Tol (2008) argue that dwelling age has a marginal effect on electricity consumption in Irish dwellings.

Besides, a study in Ireland found that rented dwellings (either including or excluding the electricity bill) have a significant impact on residential electrical energy consumption (O'Doherty et al., 2008). Conversely, Tso and Yau (2003) pointed out that rented dwellings did not significantly impact electricity consumption. On the other hand, one study reported that home ownership might impact residential electrical energy consumption indirectly (Rehdanz, 2007).

Together, these studies provide important insights into physical characteristics of dwellings and their contribution to residential electrical energy consumption. One of the most significant findings to emerge from this section is that there is a proportional relationship between dwelling size and electrical energy consumption. Dwelling type is the second major contributor to electricity consumption after dwelling size. Generally, dwelling type and building materials depend on geographical location of the dwelling. The issue of dwelling age is an intriguing one which could be usefully explored in further research in conjunction with other physical characteristics.

3.3 Household activities and services

The nature of residential electricity consumption is closely interconnected with the occupants' electricity use behaviour. It can be usefully described as 'cause and effect'.

Occupants' behaviour towards electricity use is the 'cause' and electrical energy consumption due to this behaviour is referred to as the 'effect'. It has been reported that human behaviour is responsible for about 2-25% of the variation in total residential electrical energy consumption in the USA (Kavousian et al., 2012).

The majority of previous studies have considered occupants' behaviour in limiting residential electricity consumption (Abrahamse, Steg, Vlek, & Rothengatter, 2007; Hanimann, Vinterbäck, & Mark-Herbert, 2015; Hargreaves, Nye, & Burgess, 2013; Hu, Yan, Guo, Cui, & Dong, 2017; Karlin, Ford, & Squiers, 2014; Karlin, Zinger, & Ford, 2015; Lopes, Antunes, & Martins, 2015; Nilsson et al., 2014; Osbaldiston & Schott, 2012). In turn, the behaviours that have been identified in the literature for energy conservation are also responsible behaviour for residential electrical energy consumption. Thus, energy saving related behaviours are reviewed in this section to identify the behaviours responsible for electrical energy consumption.

3.3.1 Energy-use behaviour and activities

Allcott and Mullainathan (2010) in the USA found 2.7% of electricity consumption can be reduced through behavioural interventions, such as feedback, goal setting and commitments. Similarly, the European Environment Agency reported that energy-use behaviour can affect energy consumption by 5% to 20% (EEA, 2013), which is higher than the finding in the USA (Allcott & Mullainathan, 2010).

Electricity consumption due to heating practices was investigated in retrofitted apartments in Germany, where three groups were identified, namely light (20% households), medium (57% households) and heavy (23% households) consumers (Galvin, 2013). It was emphasized that heavy consumers should be the focus to reduce electricity consumption, rather than focusing on all groups because the heavy consumers consumed around 52% of the total heating energy at houses. Another recent study in Denmark revealed that heating energy (for space and water heating) depends on sociocultural differences of the occupants (Hansen, 2016). Households with immigrants were found to be the most efficient in saving heating energy. A recent study in Austria found that consumer behaviour significantly affects household heating energy demand, which in turn is associated with electricity consumption (Holzmann & Schmid, 2018). In line with the Austrian study, Giusti and Almoosawi (2017) found that a considerable amount of electricity consumption can be saved by switching off water heating systems and air conditioners (for cooling) when not in use and setting air conditioners' thermostat temperature at 24 °C in Abu Dhabi.

Two studies have considered the relationship between TV watching activities, TV programmes and residential electricity consumption (Bunn & Seigal, 1983; Sekar et al., 2016). The recent research by Sekar et al. (2016) used time of use strategy for their study and identified three groups of people based on time spent in watching TV. It has been found that the group consisting of older, less employed and less educated people, spent 7.7 h per day by watching TV in the USA. This group represents 14% of the total population in the USA, and consumes 34% of total energy due to TV watching. Notably, TV watching time for all three groups coincides with electricity network peak time. Moreover, an earlier study by Bunn and Seigal (1983) showed that commercial breaks during popular TV programmes in the UK contribute to residential peak demand due to residents' activities during the breaks, such as using electric kettles to prepare hot drinks.

3.3.2 Use of electrical appliances

One of the main reasons for residential energy consumption is the use of household electrical appliances. A number of previous research studies have reported the impact of household electrical appliance use on residential electricity demand (Bedir & Kara, 2017; Borg & Kelly, 2011; De Almeida, Fonseca, Schlomann, & Feilberg, 2011; EEA, 2013; Firth, Lomas, Wright, & Wall, 2008; Genjo, Tanabe, Matsumoto, Hasegawa, & Yoshino, 2005; Ghisi, Gosch, & Lamberts, 2007; Gouveia & Seixas, 2016; Haas, Biermayr, Zoechling, & Auer, 1998; Kavousian et al., 2012; Lam, 1996; McKenna, Hofmann, Kleinebrahm, & Fichtner, 2018; Soares, Gomes, & Antunes, 2014; Tso & Yau, 2007). Electrical energy consumption due to the use of household electrical appliances varies from country to country, due to geographical location and related climate. In an early study, Lam (1996) identified major household electrical appliances that consume a significant amount of electrical energy in Hong Kong: air conditioning systems for cooling, and refrigerators. Similar result was also found in Greece, for the period of 1999–2000 the peak load was increased about 16% (1163 MW) due to extensive use of room air conditioners in summer (Papadopoulos, 2007). This may be true for hot countries, whereas, in cold countries, different residential energy consumption scenarios are observed. A study considered 12 European Union (EU) countries and found that approximately one-third of the total residential electrical energy consumption was for refrigeration (28%) and the second major use was for lighting (18%) (De Almeida et al., 2011). However, being a cold country, New Zealand's typical household consumes 30% of its total residential electrical energy for water heating, 16% for refrigeration, and 12% for lighting (Electricity Authority, 2016). On the other hand, residential electrical energy consumptions for space heating were 14% and 2% for New Zealand and 12 EU countries, respectively. Importantly, due to different geographical location, residential electrical energy consumption varies significantly. For instance, a typical household in Brazil accounts weighted averages of 42%, 11%, and 10% of total residential electrical energy consumption for refrigerators and freezers, lighting, and air conditioning, respectively (Ghisi et al., 2007).

On the other hand, in the USA, Kavousian & Rajagopal (2012) reported that about 8% of the total residential electrical energy consumption is due to the use of household electrical appliances and electronics. In the UK, a study identified four types of electrical appliances in households: continuous appliances, such as clocks, standby appliances (TV in standby mode), cold appliances (refrigerators), and active appliances (lights, kettles in use) (Firth et al., 2008). The study found that annual electrical energy consumption increased by 4.5% due to increases in continuous, standby and active appliances. In like manner, Soares et al. (2014) categorized household appliances (i.e. electrical load) according to the degree of control, based on end-user activities towards appliance use and their related operation in Portugal.

Appliance ownership was found to be another factor responsible for household electricity consumption in several studies (Borg & Kelly, 2011; Ghisi et al., 2007; Gouveia & Seixas, 2016; Haas et al., 1998; Singh, Mantha, & Phalle, 2018; Tso & Yau, 2007). Noticeably, there exists a positive and linear relationship between the ownership of electric showers[3], air conditioning systems and residential energy consumption (Ghisi et al., 2007).

In summary, results of this investigation show that residential electrical consumption varies due to the use of various household electrical appliances. A common reason is the time of operation of certain appliances. Most certainly, appliances, an aspect of the energy-use behaviour of the occupants. Further research on this topic needs to be undertaken before the association between household electrical appliances and energy-use behaviour of the occupants is more clearly understood.

3.4 Economic capability

Energy researchers have found that the relation between economic capability and residential electricity consumption is a key factor in residential electrical energy demand. In general, economic capability indicates the overall wealth and monthly income of the householders. Specifically, income was considered as the economic capability in the majority of the previous research and a positive relation between income and residential electrical energy consumption was found (Abrahamse & Steg, 2009a; Cayla, Maizi, & Marchand, 2011; Francisco, Aranha, Zambaldi, & Goldszmidt, 2006; Genjo et al., 2005; Gouveia & Seixas, 2016; Powers et al., 1992). Others claimed an insignificant relationship between income and residential electrical energy consumption (Kavousian et al., 2012; Sanquist, Orr, Shui, & Bittner, 2012; Tso & Yau, 2007).

Francisco et al. (2006) affirmed a strong correlation between income and residential electrical energy consumption in Brazil. Similarly, residential electrical energy consumption was studied under different bioclimatic conditions in five regions in Brazil (Ghisi et al., 2007), and it was found that in the northeast region electricity consumption was less than in other regions, one of the reasons being household income. Recently, another study in Brazil revealed that if family income rises by 1%, electricity consumption increases by 0.19% (Villareal & Moreira, 2016). Likewise, O'Doherty et al. (2008) in Ireland found that energy use increases by 0.76% for each £100 increase in household income.

Genjo et al. (2005) found a positive and linear relationship between income and annual electricity consumption in Japan. Similar relationships were also observed in other studies (Abrahamse & Steg, 2009a; Gouveia & Seixas, 2016). These relations are in line with the classic energy ladder theory: if the income of a household increases, occupants will shift their energy-use behaviour to a more advanced or sophisticated energy carrier (Hosier & Dowd, 1987; Van Der Kroon, Brouwer, & Van Beukering, 2013). Interestingly, this is contrary to a study conducted by the International Energy Agency (IEA) which reported that the energy ladder does not work straight away: when income increases, fuel (energy) options are broadened but the previous energy carrier is still maintained.[4]

Sanquist et al. (2012) found a marginal impact of income on electricity consumption in the USA. At the same time, Kavousian & Rajagopal (2012) found no significant correlation between income and residential electricity consumption in the USA. Many other studies also revealed the impact of income on electricity consumption, with differing results. Some of them found a positive relation, some a negative and others found no relation to income at all (Alberini, Gans, & Velez-Lopez, 2011; Arikawa, Cao, & Matsumoto, 2014; Copiello & Gabrielli, 2017; Davis, 1998; Farsi, Filippini, & Pachauri, 2007; Fell, Li, & Paul, 2014; Gupta & Köhlin, 2006; Meier, Jamasb, & Orea, 2012; Liu, Judd, & Santamouris, 2017; Manalo-Macua, 2007; Nesbakken, 1999; Reiss & White, 2001).

On the other hand, in terms of household wealth, Miah, Foysal, Koike, and Kobayashi (2011) found a significant positive relationship between wealth (i.e. land ownership would be one example of wealth) and energy consumption in rural households in Bangladesh (Miah et al., 2011). A similar result has also been found in Bhutan (Rahut, Das, De Groote, & Behera, 2014).

An implication of the findings from this section is that economic capability, specifically income has an influence on residential electrical energy consumption. Sometimes the influence is direct, but often it is indirect.

3.5 Socio-demographic characteristics

Different socio-demographic characteristics and factors affect residential electricity consumption directly or indirectly. Several studies have discussed lifestyle as one of the socio-demographic factors in residential electricity consumption (Bedir et al., 2013; Genjo et al., 2005; Nakagami, 1996; Salari & Javid, 2016; Sanquist et al., 2012). A significant relationship between residential electrical energy consumption and lifestyle or social status has been found in (Bedir et al., 2013) and (O'Doherty et al., 2008). In the USA, Sanquist et al. (2012) reported that about 42% residential electricity consumption varies due to occupants' lifestyle patterns: lifestyles associated with air conditioning contribute to maximum to electricity consumption. In-house electrical appliance use evolves with lifestyle. An early study in Japan found that 58 GJ of energy per household per year is required for in-house comfort with the use of energy efficient electrical appliances and central heating and cooling systems (Nakagami, 1996). Another study in Japan found that the number of electric appliances varies considerably with respect to the lifestyle or social status of the families (Genjo et al., 2005). Although lifestyle is one of the causes of residential electrical energy consumption, it also strongly depends on household income as identified by Yan and Minjun (2012) in China.

In case of occupants' age, O'Doherty et al. (2008) found a nonlinear significant impact on residential electrical energy consumption. Other studies also found a relationship between occupants' age and electrical energy consumption (Bedir et al., 2013; Shimokawa & Tezuka, 2014). In contrast, a few studies did not find occupants' age as one of the significant factors for residential electrical energy consumption (Abrahamse & Steg, 2009a; Gatersleben, Steg, & Vlek, 2002; Poortinga, Steg, Vlek, & Poortinga, 2004).

The relationship between gender and residential electrical energy consumption has been found to be inconsistent in previous research. Some studies have explored pro-environmental attitudes and the behaviour of men and women in relation to household electricity consumption, and found that women have more pro-environmental attitudes and behaviour than men (Barr, Gilg, & Ford, 2005; Clark, Kotchen, & Moore, 2003; Kollmuss & Agyeman, 2002; Zelezny, Chua, & Aldrich, 2000). These findings were in line with (Shimokawa & Tezuka, 2014) in Japan. They reported that females use less energy in households than males. Likewise, a study in the UK noted that females were more aware of residential electricity consumption than males, although the number of female respondents (38.4%) was higher than that of males (30.5%) in that study (Mansouri, Newborough, & Probert, 1996). A similar result was also found in Bhutan (Rahut et al., 2014). Conversely, a few other studies have found no influence of gender on residential electricity consumption (Abrahamse & Steg, 2009a; Abrahamse & Steg, 2011; Poortinga, Steg, Vlek, & Wiersma, 2003; Sardianou, 2007).

Education plays an important role in residential electrical energy consumption. Educated people are more aware of electricity consumption than the less educated. It has been reported that those who spent many years in education save more energy than those with less education (Arikawa et al., 2014; Gram-Hanssen, Kofod, & Petersen, 2004; Mansouri et al., 1996; Powers et al., 1992). In contrast, the opposite result has also been found in China and Ireland (Leahy & Lyons, 2010; Zhou & Teng, 2013); the authors reported that highly educated people consume more energy than less educated. A similar result was also found in Bangladesh, where rural household energy consumption increases with increasing of literacy rates (Miah et al., 2011). Education also helps people to choose the latest energy source. For example, the choice of lighting types in relation to education is explained in Bhutan (Rahut et al., 2014). Apart from these, Bedir et al. (2013) and Cramer et al. (1985) did not find any relationship between education and electricity consumption in Dutch and US households.

The number of occupants, often referred as 'household size' is also a vital factor in residential electrical energy consumption and has been extensively researched in the literature. Most previous studies have reported a positive relationship between electricity consumption and number of occupants in a household (Bedir et al., 2013; Brounen, Kok, & Quigley, 2012; Druckman & Jackson, 2008; Kavousian, Rajagopal, & Fischer, 2013; Miah et al., 2011; Ndiaye & Gabriel, 2011; Powers et al., 1992; Tiwari, 2000; Wiesmann et al., 2011; Yohanis et al., 2008). That is, if the number of occupants in a household increases, electrical energy consumption will also increase. It has been reported that an additional occupant in a household will increase electricity consumption by 7.7% in India (Tiwari, 2000). Similarly, Brounen et al. (2012) found a 21% increase in electricity consumption for an additional occupant in Dutch households. The reasons behind this variation in consumption could be the economic conditions and lifestyle patterns of the occupants in those two countries. On the other hand, Tso and Yau (2003) found the number of household members was not a significant factor in winter residential energy consumption, but it was in summer in Hong Kong. Likewise, a negative relationship was found between electrical energy consumption and number of occupants in a household in India (Filippini & Pachauri, 2004). Many other found insignificant relationship between the number of occupants and electrical energy consumption (Bartusch et al., 2012; Carter, Craigwell, & Moore, 2012; Shimokawa & Tezuka, 2014; Yohanis et al., 2008). Notably, the number of occupants was found as one of the key drivers of residential peak demand in Australia (Fan et al., 2017).

Family composition, which can be defined as the presence of different age groups – children, teenagers, adults and elderly people – in a household, is another notable factor which contributes to residential electrical energy consumption. The majority of studies found a significant impact on residential electrical energy consumption due to family composition (Bartusch et al., 2012; Brounen et al., 2012; McLoughlin et al., 2012; McLoughlin et al., 2015; Wiesmann et al., 2011; Wyatt, 2013; Zhou & Teng, 2013). As an illustration, Wiesmann et al. (2011) found a significant influence of household characteristics, such as number of household occupants and children, on residential electricity consumption. Furthermore, McLoughlin et al. (2015) have considered household composition as a variable in their residential load profile characterization, and found a strong correlation with residential electricity consumption in Ireland. Conversely, some other studies found an insignificant relationship between residential electrical energy consumption and family composition (Bartiaux & Gram-Hanssen, 2005; Bedir et al., 2013; Leahy & Lyons, 2010).

Although occupational status of occupants was found to be insignificant regarding residential electrical energy consumption (Yohanis et al., 2008), occupational working hours might have an impact on it. With this in mind, if an occupant is present in the workplace at a different time rather than usual office hours, the electrical energy consumption scenario will be different for that household compared with households with people who observe regular office hours. This variation occurs due to occupants' presence at home

(Diao, Sun, Chen, & Chen, 2017). Very few studies have considered occupational status in relation to household electricity consumption, but one example is Hansen (2016) in Denmark, who found that heat consumption was high for households with higher income and occupational status (Hansen, 2016). On the other hand, in a recent study, occupation has been considered as a variable of analysis in Nepalese households to identify the effects of income on access to electricity (Bridge, Adhikari, & Fontenla, 2016).

Taken together, these findings suggest a role of socio-demographic characteristics in influencing household electrical energy consumption. It is clear from the above discussion that lifestyle is one of the reasons for residential electrical energy consumption. In like manner, occupants' age is also a contributing factor. Furthermore, highly educated people are found to be more concerned about electrical energy-use than the less educated. In addition, residential electrical energy consumption is strongly influenced by the number of occupants in a household. Most previous studies suggest that if there is an increase in the number of household occupants, electrical energy consumption starts to escalate accordingly. Moreover, families with children and elderly people consume more electricity than those with adults only. There are few studies in the literature that discuss the relationships between gender, occupational status, and electrical energy consumption. Studies about the role of occupants' race and cultural factors towards residential electrical energy consumption also seem not covered well in the literature, and this would be an interesting area to investigate.

3.6 Cost of energy

The cost of electrical energy is also related to electricity consumption. O'Doherty et al. (2008) found that off-peak electricity tariffs have an impact on electricity consumption. The study identified that about 2.1% energy-use can be increased in a dwelling due to off-peak electricity tariffs in Ireland. Furthermore, the relationship between economic factors and energy-use behaviour has been investigated in (Villareal & Moreira, 2016), which found that if electricity tariffs are increased by 1%, electricity consumption decreases by 0.23%. A recent study in the USA has found that the average electricity price is a significant factor in residential electrical energy consumption (Salari & Javid, 2016), and reported that policymakers could control the average electricity price to reduce residential electricity consumption. On the other hand, a survey was conducted in Japan and found that electricity price is not a major determinant of electricity consumption for the use of different electrical appliances (Yamamoto, Suzuki, Fuwa, & Sato, 2008). The authors concluded that residential electrical energy consumption is not only influenced by the variation of electricity rate and the use of appliances, but also strongly correlated with consumers' attitudes and belief. This result is closely related to the finding of (Thorsnes, Williams, & Lawson, 2012): in the case of time of use (TOU) tariffs, peak and off-peak rates per unit of electricity, with a slight difference, do not have noticeable impacts on average electrical energy consumption. Many other studies have also investigated the impact of TOU tariff on peak electricity demand (Laicane et al., 2015; Powells et al., 2014), and found that TOU tariff can contribute to peak electricity demand variation in the range of 1% to 6% (Newsham & Bowker, 2010; Nicholls & Strengers, 2015; Spees & Lave, 2008). On the other hand, much less attention has been paid to policy-related research that deals with residential energy consumption (Labidi & Abdessalem, 2018).

It is clear that the cost of energy-use can have an impact on electrical energy consumption for two reasons: firstly, it depends on the economic condition of the consumers and it is also associated with the energy-use attitudes and belief of the householders.

3.7 Potential drivers of future residential consumption

Electric vehicles (EV) will be the dominant form of road transport in the near future. Although at present the price of EVs is higher than that of liquid fuel driven vehicles, EVs are becoming more popular by the day for their environmentally friendly operation. Consequently, EV uptake will impose an impact on electricity networks due to their battery charging requirements (Moon, Park, Jeong, & Lee, 2018). This will be one of the major electricity consuming items at residences in the near future (Aghaei, Nezhad, Rabiee, & Rahimi, 2016; Boßmann & Staffell, 2015; Clement-Nyns, Haesen, & Driesen, 2010; Hindsberger, Boys, & Ancell, 2012; New Zealand Centre for Advanced Engineering, 2010; Shafiee, Fotuhi-Firuzabad, & Rastegar, 2013; White & Zhang, 2011).

As an illustration, consider 1.5 million EV uptakes in New Zealand by 2040; each EV requires 1 kWh electrical energy to run each 5 km, a total 40 km per day, and to support this charging rate, annual electrical energy requirements will increase by 1%. It has been reported that if 500,000 EVs start charging at 6 pm after returning to their owners' houses, there will be an increase of 1.5 GW load within 30 min (Hindsberger et al., 2012). This represents 20% extra peak demand during peak periods. A model developed by Shafiee et al. (2013) has been tested on different residential distribution networks in different time zones and found that major impacts of EVs in distribution network will increase peak load and network loss. The problem will become even more complex during winter, when the network load increases due to space heating activities. In line with this result, voltage deviation, power loss, and peak load increment have also been reported in another study in Belgium (Clement-Nyns et al., 2010). In an earlier study, Qian, Zhou, Allan, and Yuan (2011) found that penetration of 10% EV in the typical UK distribution system would result in 17.9% demand during peak periods. A recent report estimated that without smart charging systems EVs would add an extra 8 GW of demand during peak hours in the UK electricity system (National Grid, 2017). This is in line with another study in Portugal, in which the authors found that '…..*EVs can be a feasible option for shaving the peaks of the electricity load profile, while valley filling can be effective once control practices for charging the vehicles are implemented*' (Ioakimidis & Genikomsakis, 2018).

Neves, Marques, and Fuinhas (2018) in Portugal concluded that energy security could be compromised if a large number of EVs start to charge at the same time. Similarly, an electrical peak demand projection by 2050 for Germany and Britain has been conducted in (Boßmann & Staffell, 2015) and estimated that due to uncontrolled charging of 15–23 million electric vehicles, there will be an additional peak load of 101–105 GW and 91–92 GW in Germany and Britain, respectively.

Interestingly, developing countries are also adopting electric vehicles. In particular, Bangladesh introduced its first electric three-wheelers (called 'Easy Bike' or 'Auto Rickshaw') in 2004 (Ali, 2011). In 2014, the number of easy bikes was more than 400,000 across the country (Rasel, 2014). Most of these easy bikes are charged at their owners' residences. Normally, an easy bike's battery takes 4–5 h to be fully charged. This charging time coincides with the evening peaks, which results in a power cut (load shedding) during peak demand period, as in Bangladesh demand of electricity is higher than the generation capacity during peak hours (Khan & Halder, 2016). The situation will worsen in the near future as the average growth rate of easy bikes is 43% per year (Rana, Hossain, Roy, & Mitra, 2013). This peak demand problem in relation to EVs also exists in other developing countries. For example, it was found that a 10% increase in EVs would result in a 2% increase in electricity demand for a state in Brazil (Dias et al., 2014). On the other hand, to avoid peak demand problems and ensuring system reliability, a vehicle-to-home and vehicle-to-grid strategies were proposed by Kumar, Anmol, and Akhil (2015) and Reddy, Goswami, and Choudhury (2018), respectively in India.

Although electrical home appliances are becoming more efficient due to technology development, the increasing number of electrical home appliances, especially space conditioning appliances (air conditioners, room heaters) will also drive residential electricity consumption in the near future. For example, a projection-based study has reported that a million extra heat pumps in winter will add 1.2 and 0.8 GW of load to national peaks by 2050 in Germany and Britain, respectively (Boßmann & Staffell, 2015). Recent report of 'National Grid' in the UK estimated that the '*… .air conditioning could raise peak demand in summer to a similar level to winter …* .' (National Grid, 2017).

The growing number of EVs and space conditioning electrical home appliances will thus have important implications for electrical networks in the near future. Consequently, not only additional generation of electricity is required, but also transmission and distribution networks need to be upgraded and enhanced to support this extra peak demand during peak times.

4. Discussion

In reviewing the literature, internal and external factors identified and associated with residential electrical energy consumption are climatic effect, location of residence, occupants' behaviour, socio-demographic characteristics, physical characteristics of dwellings, economic capability, cost of energy-use, varieties of electrical appliances including electric vehicles, and policies. It is worth mentioning that these factors are dependent on different sub-factors. For instance, socio-demographic characteristics include but are not limited to: family composition, occupants' age, occupation, education, gender, technical skills, social status, cultural factors, lifestyle and number of occupants.

This review clearly indicates that few residential electrical energy consuming factors have direct contributions to residential peak demand. In contrast, few have indirect impacts. For example, climatic effect such as temperature is identified as an external factor directly contributing to residential peak demand through space conditioning home appliances (Kros, 2015; Lam et al., 2008, 2005). On the other hand, physical characteristics (e.g. thermal response of building, building materials) of the dwelling have been identified as a factor indirectly contributing to residential peak demand (Date, Athienitis, & Fournier, 2015; Lee & Medina, 2016; Turner, Walker, & Roux, 2015). However, the relationships between many other residential electrical energy consuming factors and residential peak demand have still not been explored in the literature. Thus, the most obvious finding to emerge from this review is that the majority of previous studies have dealt with the factors responsible for residential electrical energy consumption rather than electrical peak demand generating from residences. A summary of the findings from this review are presented in Table 1.

Table 1. Summary of findings: factors responsible for residential electrical energy consumption and peak demand.

Factors	Sub-factors	Contributions to Residential Electrical Energy Consumption	Contributions to Peak Demand	Percentage of Contribution/ Relationship	Discussed in sub-section
Climate and location of the dwelling	1. Temperature 2. Wind 3. Humidity 4. Geographical location	• Temperature and geographical location of the dwelling were found as the significant contributors. • Wind and humidity have an insignificant contribution.	• Temperature (considered in few studies).	• 1.5-15.3% [*Peak demand*] Reason: If temperature is increased by 1~3.5^{0}C.	3.1
Physical characteristics of dwelling	1. Dwelling size (number of bed rooms, floor area) 2. Type of dwelling (degree of detachment) 3. Dwelling materials 4. Age of the dwelling	• Dwelling size • Type of dwelling • Dwelling materials, however, type of the materials depend on climate and geographical location of the dwelling. • Dwelling age is an intriguing one which needs further exploration, as some studies found an insignificant relation; some found no relation; and few found a marginal contribution to residential electrical energy consumption.	• 'Type of dwelling' contributes significantly to residential peak demand.	• 2-5% [*Energy consumption*] Reason: Due to overall physical characteristics of dwelling.	3.2
Household activities and services	1. Energy-use behaviour 2. Use of electrical appliances 3. Appliance ownership	• Use of electrical appliances in association with occupants' energy-use behaviour was found as one of the potential contributors to residential electrical energy consumption. • Appliance ownership has also an impact on household electricity consumption.	• Use of in-house electrical appliances and peak demand have been investigated in few studies and found a significant relation. • Energy-use behaviour towards electricity savings has been explored in many previous studies. However, there was no attempt made to explore the relationship between energy-use behaviour and electrical peak demand.	• 2.7-20% [*Energy consumption*] • Reason: Due to energy-use behaviour. • 4.5-8% [*Energy consumption*] • Reason: Due to use of electrical appliances. • 16% [*Peak demand*] • Reason: Due to use of electrical appliances (room air conditioners).	3.3
Economic capability	1. Income 2. Wealth	• Some of the previous studies found a positive relation; few found a negative relation; and other found no relation between income and residential electrical energy consumption. • Very few studies have explored the relationship between wealth and residential electrical energy consumption.	• Not explored.	• Overall, a positive relation was found between economic capability and electricity consumption.	3.4
Socio-demographic characteristics	1. Age	• Age has been found as one of the inconsistent factors in the literature towards residential electrical energy consumption. Some studies	• Not explored.	• A non-linear relationship was found between age and electricity consumption.	3.5

(*Continued*)

Table 1. Continued.

Factors	Sub-factors	Contributions to Residential Electrical Energy Consumption	Contributions to Peak Demand	Percentage of Contribution/ Relationship	Discussed in sub-section
		found a non-linear relationship; whereas, other studies were unable to detect any relationship.			
	2. Gender	• Although women were found more pro-environmentally behaved than men, this is not consistent in the literature. Many other studies could not detect any significant relationship between gender and residential electrical energy consumption.	• Not explored.	• Need further exploration. However, females are found more aware of energy-use than males.	3.5
	3. Education	• Education may influence the pro-environmental behaviour. However, previous research does not support the consistency of this proclamation.	• Not explored.	• Need further exploration. Education could play a vital role towards energy efficiency and DSM measures to reduce electricity demand.	3.5
	4. Employment/ Occupational status	• Household income could be influenced by the employment/occupational status of the occupants. Thus, employment status might have an impact on residential electrical energy consumption from an economic point of view. Moreover, working hour of the occupants may change the residential electrical energy consumption pattern.	• Not explored.	• Need further exploration.	3.5
	5. Number of occupants/ Household size	• Majority of the previous research studies have found a proportional relationship between the number of occupants/household size and residential electrical energy consumption. That is, if the number of occupants in a residence is increased, electrical energy consumption will also increase accordingly. However, per capita energy consumption will be lower for large household than small one.	• Found significant relationship.	• 7.7-21% [*energy consumption*] Reason: Due to an additional occupant in a household.	3.5
	6. Family composition	• Family composition has been found as one of the driving factors towards residential electrical energy consumption. A reasonable body of research has found almost consistent relation between family composition and residential electrical energy consumption.	• Not explored.	• Strong relationship was found between family composition and electricity consumption.	3.5
	7. Lifestyle/Social status	• Lifestyle or social status might impact residential electrical energy consumption indirectly.	• Not explored.	• Need further exploration.	3.5

		Because lifestyle is one of the dependent factors; which depends on many other independent factors such as economic capability of the household.			
Cost of energy	1. Electricity tariff 2. Policy	• Electricity tariff has an impact on residential electrical energy consumption. • Further investigation required to explore the relationship between policy and electricity consumption	• As a demand side management strategy- 'Time of Use' tariff has been investigated with peak demand. However, the relation between costs of energy associated with energy policy and peak demand yet to explore.	• 1-6% [*Peak demand*] Reason: Due to 'time of use' tariff.	3.6
Potential drivers of future residential consumption	1. Electric vehicle (EV) 2. Increasing number of electrical home appliances	• Electric vehicle and increasing number of electrical home appliances will contribute significantly towards residential electrical energy consumption in the near future.	• Many simulation studies have investigated the impact of EVs on peak demand and found a significant relation.	• 17.9-20% [*Peak demand*] Reason: Due to different percentages of EV penetration into the transport sector.	3.7

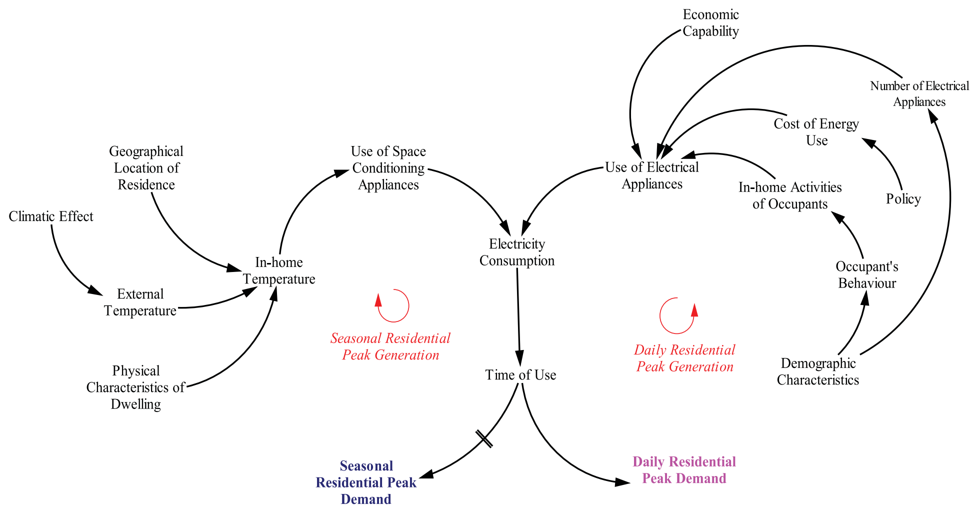

Figure 2. Causal relationships between seasonal, daily residential peak demands and associated factors ('||' in the arrow indicates delay or lengthy period of time).

The findings from this review provide a conceptual premise of relationships that exist between the factors responsible for residential electrical energy consumption and electrical peak demand. Hence, the causal relations between daily and seasonal residential peak demand, and the factors that contribute to residential electrical energy consumption can be hypothesized (see Figure 2).

4.1 Daily residential peak

Noticeably, daily residential electricity consumption is the result of regular activities of occupants. One of the major factors for daily residential electricity consumption is the use of different electrical appliances during peak hours. The next factor is the occupants' socio-demographic characteristics. Among all the socio-demographic characteristics, family composition, age of the occupants and number of occupants at dwellings are the most influential factors, in conjunction with appliance use. In the near future, electric vehicles will be one of the significant contributors to daily residential electrical demand due to battery charging requirements. Therefore, daily residential peak demand is more influential on daily network peaks than commercial and industrial peaks, because it is generated from households through the use of different electrical appliances during peak hours in association with various socio-demographic characteristics of the occupants (cf., Figure 2).

4.2 Seasonal residential peak

Seasonal residential peak demand depends on climatic conditions and any other event associated with electricity consumption. For example, electrical peak demand during winter (June to August) in New Zealand and the scorching summer season in Bangladesh (April to October) are seasonal peak demands, when electricity demand is high due to space conditioning appliances. This suggests that seasonal residential peak is prominent when climatic factors such as temperature dominate in-home energy-use behaviour of the occupants (cf., Figure 2).

4.3 Uncertainty of peaks

Daily residential peaks are unpredictable, as they depend on a number of factors such as the use of in-home electrical appliances, socio-demographic characteristics, and energy-use behaviour of the occupants. Seasonal residential peak is similarly unpredictable, and is mainly influenced by the climate and can change at any time. However, weather forecasts could provide indications of climatic changes and associated electricity demand. Therefore, daily residential peak demand is relatively more uncertain, and it imposes a greater risk to the electrical network than seasonal peak, as it deals with the unpredictable daily energy-use behaviour of the occupants at residences.

4.4 Energy-use dynamics

According to (Chatterton, 2011, p. 5) '*Behavior is the action, reaction, or functioning of an organism or system, under normal or specified circumstances*'. Human behaviour towards energy-use can be explained by the combination of four different fields (Chatterton, 2011) namely economics, psychology, sociology, and education as depicted in Figure 3.

This energy-use behaviour varies from one person to another. Some people are influenced by economic aspects or psychological reasons whereas others are motivated by social practices or education, and it is often a combination of two or more variables. In the light of this review, these variables can be interpreted as energy price, skill, energy-use practice, and feedback for economics, education, sociology, and psychology, respectively, as shown in Figure 3.

For future studies to explore the relationships between household factors and electrical peak demand, it is essential to understand the in-house energy-use dynamics of the occupants. In conjunction with the variables shown in Figure 3 and factors identified from the literature, how in-house electrical energy-use behaviour evolves is illustrated in Figure 4.

Residential electrical energy-use behaviour evolves in a cyclic order as shown in Figure 4. A change in residential energy-use behaviour can be initiated by a motivation. This motivation can be gained from social or individual activities (e.g. new product campaign, environmentally friendly campaign), or even from a government's energy-

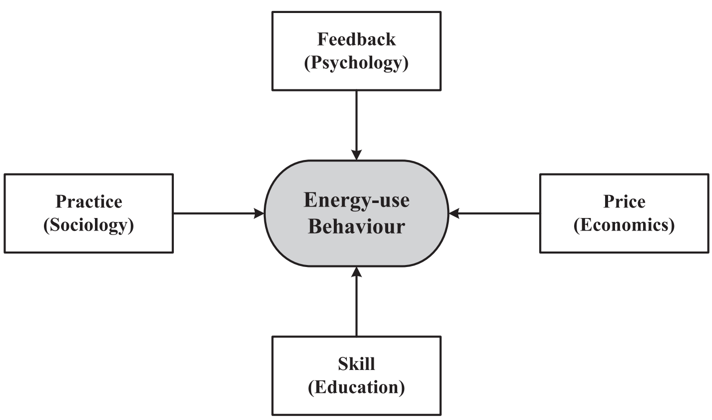

Figure 3. Variables that influence the energy-use behaviour.

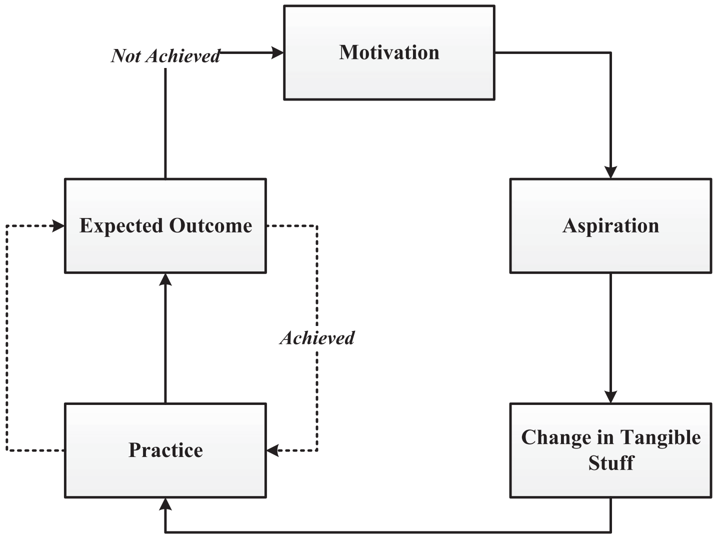

Figure 4. In-house electrical energy-use dynamics.

use policy. This motivation is directly connected to aspiration which is defined as 'a hope or ambition of achieving something'. This aspiration leads to the required change in tangible activities to fulfil the desired goal. These include physical characteristics of dwellings, household electrical appliances and electric vehicles. The next step is related practice associated with these activities. The practice is also interrelated with socio-demographic characteristics, economic ability, cost of energy, and occupants' behaviour. The last step is the measure of the expected outcome. If the expectation is achieved, the practice and expected outcome cycle continue. Otherwise, the process starts again from the motivation step.

5. Implications for future study

To better understand and reveal the factors involved in residential electricity consumption and peak demand, it is essential to follow a systematic analysis approach. In view of the factors found in the literature, a conceptual framework is illustrated in this section, which will identify potential factors in residences that are responsible for residential electricity consumption, as well as peak demand.

Deduction of new information from known characteristics and use of this information for some purposes is known as profiling (Ferraris, Bosco, Cafiero, D'Angelo, & Suloyeva, 2013). Thus, extrapolation of information from residential electrical energy-use patterns to understand residential peak demand characteristics can be referred as residential electrical energy profiling (REEP). It involves a bottom-up approach, which includes step by step investigation to obtain an entire energy-use scenario of households, as depicted in Figure 5.

The first step in REEP deals with climatic data and households' location analysis, which involves investigation of climatic data, households' geographical location, and related energy consumptions. For example, if a household is located in a hot and humid climatic

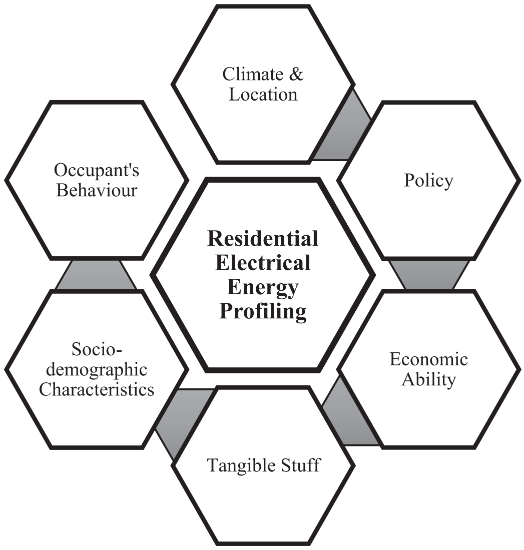

Figure 5. Residential electrical energy profiling steps.

zone, this step will be analyzing the historical weather data for maximum and minimum temperature, temperature fluctuations due to weather changes, and wind impact on temperature. The policy step encompasses analyzing the government's electrical energy use policy, subsidies, and other incorporated policies such as market and trade policy within the region. The economic ability step deals with households' income and wealth. The fourth step, tangible activities, investigates households' electrical energy consumption due to the use of various in-house electrical appliances, their associated costs, efficiency, and operation. This step also includes exploration of physical characteristics of dwellings. The fifth step inspects socio-demographic characteristics of households in relation to electrical energy consumption. The final step comprises occupants' behaviour, which considers in-house energy-use behaviour of the occupants and overall residential energy-use practice. All these steps together will allow energy-use pattern of the studied households to be understood; however, to identify the dominating factors of electrical peak demand from residences, these factors need to be compared with different time frames in relation to different peaks in demand. For example, to identify factors from residences that are responsible for daily peak demand, the last three steps need to be considered with respect to daily peak demand time. In addition, a temporal analysis approach including different household factors might be an effective way to identify the household factors that dominate others across the time periods under consideration.

6. Conclusion

The present work has investigated the literature, firstly, to identify the factors that are responsible for residential electrical energy consumption, and secondly, to explore possible relationships that may exist between these residential factors and peaks in demand. Very few factors have been explored in previous studies that investigated the direct relationship between residential factors and peak demand. Most studies focused on residential total electrical energy consumption, rather than residential peak demand. No research has been found that explored interrelations among the factors of residential electrical energy consumption and related residential peak demand.

To deal with this electrical peak demand problem generated from residences, a realistic understanding of residential electrical energy-use pattern is required. Residential electrical energy profiling could be a potential solution to understanding the underlying factors of residential peak demand and to characterize residential peak demand. In addition, the proposed framework for residential electrical energy profiling will also be able to identify any relationship between different household factors and peaks in demand. A time-varying demand analysis approach across the day might be an effective way to do so. Overall, this review could provide a useful starting point towards future research that will deal with residential factors and electrical peaks in demand.

Notes

1. Data source: http://www.emi.ea.govt.nz/
2. Pequot Publishing Inc. (February 2008). Gas Turbine World Handbook 2007–2008: Vol. 26
3. This type of shower heats the water instantaneously by a heating element and then mixes hot and cold water to obtain the final water temperature for use.
4. World Energy Outlook 2006, Chapter 15 - Energy for Cooking in Developing Countries, p. 422.

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ORCID

Imran Khan http://orcid.org/0000-0002-0716-4644

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